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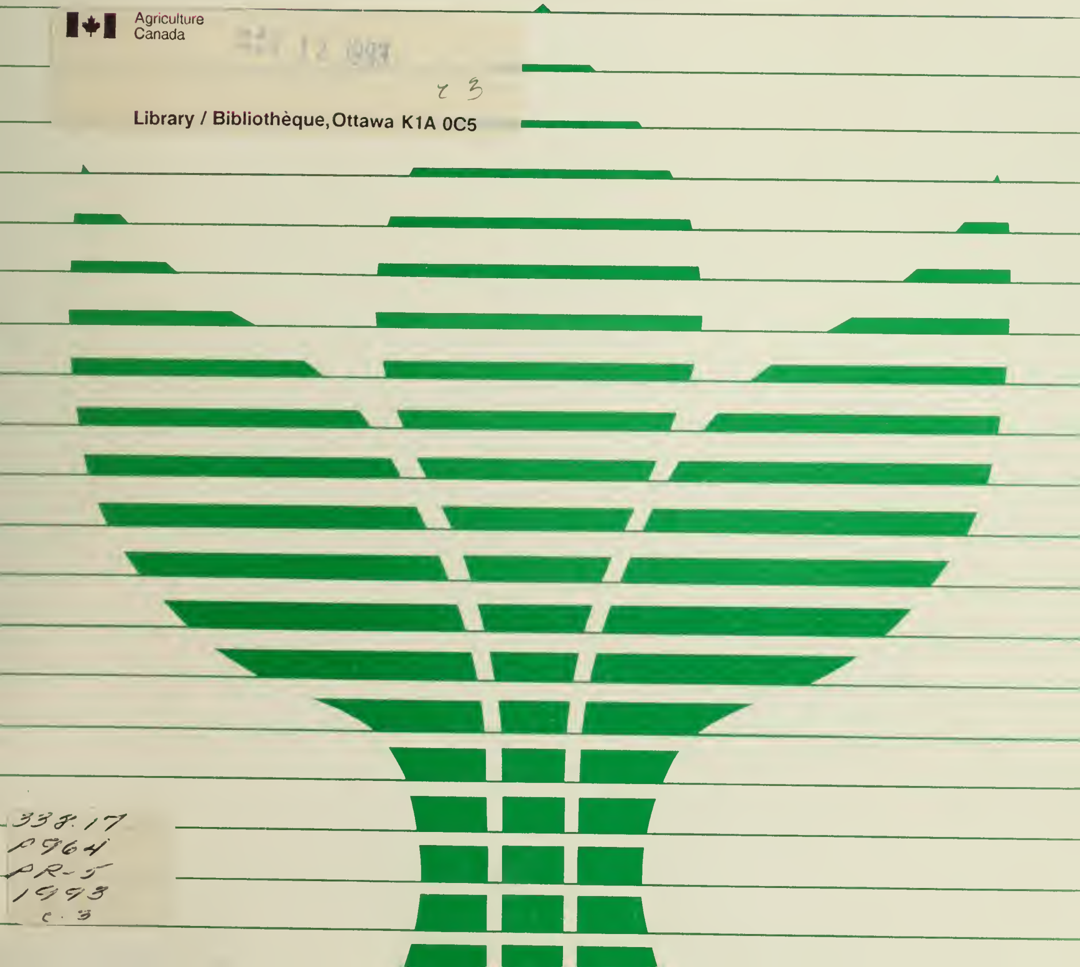
AFDA TDP-45

Evaluation of Subsoiling on Forage, Cereal Grains and Soils



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AFDA TDP-45

Evaluation of Subsoiling on Forage, Cereal Grains and Soils

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Resource Research

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EXECUTIVE SUMMARY

This project was funded by Agriculture Canada under the Technology Development Program of the Canada Nova Scotia Agri-Food Development Agreement.

The objective of the project was to evaluate the effect of subsoiling on forages, grains and soil characteristics.

Two sites were selected, one in Hants county (site 1) and one in Colchester county (site 2). Site 1 was classified as an imperfectly drained, loam (Queens) soil. Site 2 was classified as an imperfectly drained, gravelly sandy loam (Hansford) soil. Both sites had been previously tile drained with laterals at 12 metre spacings. Site 2 was subsoiled in late July and site 1 in early September 1989.

Treatments consisted of subsoiling at depths of 35 cm and 50 cm versus no subsoiling. Data was collected in 1989, 1990 and again in 1992 on soil density and hydraulic conductivity.

Soil trafficability was assessed by measuring soil penetration resistance, soil shear strength and soil moisture. Data was collected in 1990 and 1991.

Both sites were seeded in the spring of 1990. Site 1 was seeded to cereal grain, followed by faba beans in 1991 and a permanent grass/legume mixture in 1992. Half of site 2 was seeded to alfalfa/timothy and the other half to red clover/timothy. In 1991, the legume forage crops at site 2 were winter killed. The site was reseeded in the spring of 1991. Crop data was collected in 1990, 1991 and 1992.

Analysis of the data indicated red clover yields were greater on the subsoiled plots than the non-subsoiled plots. The alfalfa yields on the subsoiled plots were slightly higher than the non-subsoiled plots. No yield data was collected from the cereal grain plots.

Survival rates for both legume forage crops were poor on the nearly level land at site 2 even with tile drainage and subsoiling. Red clover yields, however, were substantially better on the subsoiled plots. Soil density and hydraulic conductivity measurements indicate subsoiling did reduce the soil density and increase the hydraulic conductivity in the first year after subsoiling but 3 years after subsoiling this improvement declined. Analysis of the soil penetration resistance, soil shear strength and soil moisture data did not indicate any differences among treatments.

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Plot survey was completed by John Sullivan of the Nova Scotia Department of Agriculture and Marketing.

Field sampling was assisted by Tracey Smith, Danielle Michaud and Wade Wheadon.

Yield data and plant counts were collected by Alden Knight of the Nova Scotia Department of Agriculture and Marketing.

Soil analyses was completed by the Analytical Services Lab of the Plant Industry Branch of the Nova Scotia Department of Agriculture and Marketing.

Root counts were collected by Dave Langille of Agriculture Canada who also assisted in the soil classification of site 2.

Subsoiling was completed by Gerard MacDonald.

Dave Grimmett of Agriculture Canada assisted in statistical analyses.

The cooperation of farmers Herman Jurrlink and Bruce Leck was greatly appreciated.

This report was edited by John Higgins of Nova Scotia Department of Agriculture and Marketing and Ken Webb of Agriculture Canada.

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INTRODUCTION

Natural occurring dense subsoils and poor internal drainage are two of the most common problems associated with agricultural soils in Nova Scotia (Hilchey, 1970). Approximately 32 percent of the agricultural soils in the Atlantic Provinces are affected by undesirable soil structure or low permeability (Nowland, 1975). It has been observed throughout Nova Scotia that after a few years, alfalfa fields have plants growing over the tile lines only (Figure 1.).

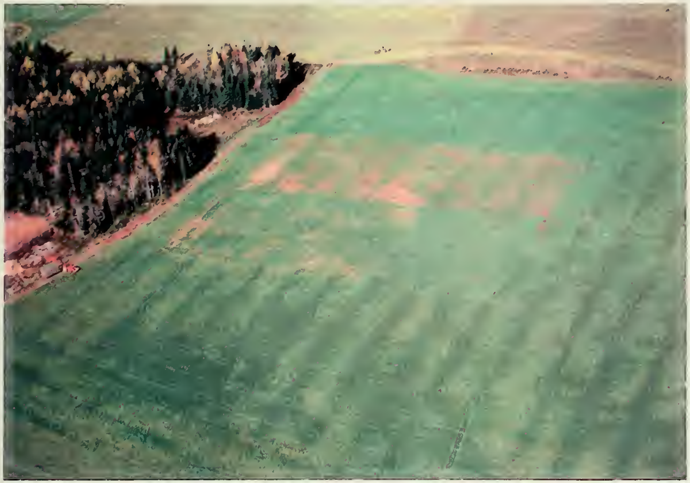

Figure 1. Alfalfa plants growing mainly over the tile lines at site 2.

Subsoiling is a deep tillage operation which loosens the soil without inverting it. In combination with subsurface drainage, it is hoped that subsoiling will increase rooting depth and increase the rate of water movement in the loosened subsoil.

Researchers have attempted to use subsoiling (Bernier et al., 1989) and subsurface drainage (Neenan et al., 1978; Broughton 1975; Smedema and Rycroft, 1983) to alleviate the problems of poor drainage and compact soils. Subsoiling has been shown to increase infiltration rates and decrease soil density, although this effect may only last 12 to 20 months (Anonymous, 1981; Busscher et al., 1986; Hipps and Hodgson, 1988). Some researchers have reported yield increases due to subsoiling while others have reported either a zero or a negative effect (Anonymous, 1981; Goit and Mellish, 1981; Michilica, 1984; Michilica, 1987; Sene et al., 1985; Unger, 1979).

Besides an improvement in crop performance, improved soil trafficability is considered an

important benefit from subsoiling (Bornstein and Hedstrom, 1981). Soil trafficability can be measured indirectly by measuring soil strength. Soil strength can be determined by shear vane or soil penetrometer (Perumpral, 1983; Ohu et al., 1988; Paul and De Vries, 1979; Carter, 1988). In addition, soil trafficability is directly related to moisture content of the soil (Smedema and Rycroft, 1983).

It is estimated that if subsoiling increased yields by 10 percent producers could benefit by approximately $1.3 million annually. This estimate is based on the following assumptions: 80,000 ha of land are seeded to hay and cereal grains (Agricultural Statistics, 1987); 30 percent or 24,000 ha are affected by shallow to compact subsoil; average economic yield is $560 per ha (Swinkels, personal communication); a 10 percent increase in yield would result in an average increase of $56 per ha or $1.3 million. If subsoiling is not beneficial, producers could be losing approximately $1 million annually. This estimate is based on the following assumptions: 24,000 ha affected by shallow to compact subsoil; average cost of subsoiling is $125 (Michilica, 1984; Swinkels, personal communications) per ha; if 33 percent or 8000 ha are subsoiled every year then the cost would be $1 million.

This project was initiated to evaluate the effect of subsoiling on crops and soils. Two soil types were selected, namely Queens and Hansford. These soil types have a compacted till subsoil which starts at a depth of 30 to 40 cm from the surface. By subsoiling into this zone it is hoped a better root environment will be produced. The project evaluated the following soil properties: soil density and hydraulic conductivity. In addition, soil trafficability was assessed by measuring soil penetration resistance, soil shear strength and soil moisture.

Data was collected on crop yields. In addition, plant counts were collected for the forage crops to determine if subsoiling improved survival rates. Root counts were taken at a depth of 20, 30 and 45 cm to see if subsoiling increased rooting depth.

MATERIALS AND METHODS

Site location and plot design

The sites were located in Hants (Site 1) and Colchester (Site 2) Counties (Figure 2). Both sites have systematic subsurface drainage systems installed in 1984 (Site 2) and 1988 (Site 1) with tile spacings of 12 meters.

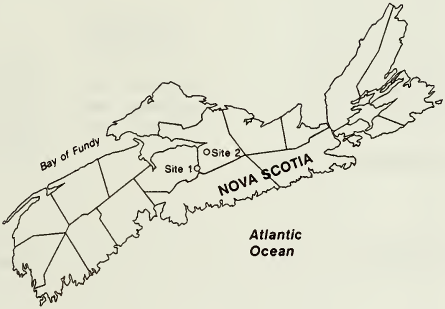

Figure 2. Site locations.

Plots were established according to a Latin square experimental design replicated 3 times. Each plot was 24.4 meters by 15 meters in size. Treatments consisted of subsoiling (0.6 meters between shanks) with a John Deere subsoiler (Figure 3) at depths of 35 cm and 50 cm versus no subsoiling (control). The subsoiler had wings on both sides of the shank which provided a 30 cm cut. The wings were at an angle of 30 degrees from horizontal. Subsoiling was done perpendicular to the tile lines (Figure 4). At site 1 the subsoiler was pulled with a Hesston 160-90 (160 hp) tractor, at site 2 a Hesston 110-90 (110 hp) tractor was used.

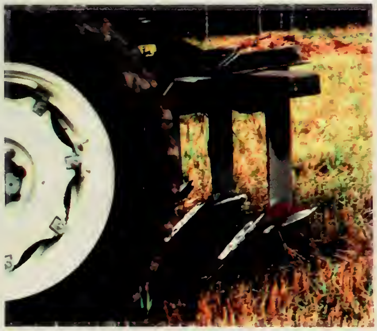

Figure 3. Subsoiler.

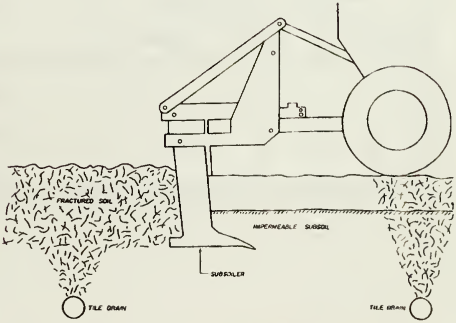

Figure 4. Schematic of the subsoiler at work.

Site 1 was subsoiled in September 1989. Site 2 was subsoiled in July 1989 and was ploughed to a depth of 20 cm in the fall of 1989. The plot plans for both sites are shown in Figures 5 and 6.

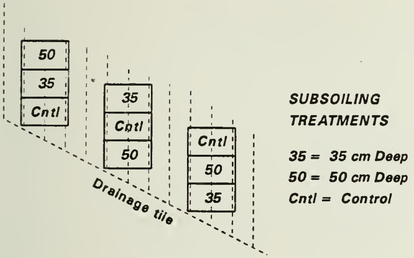

Figure 5. Plot plan for site 1.

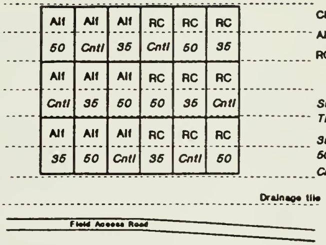

Figure 6. Plot plan for site 2.

Soil description

The soils were described according to Day, 1983. Site 1 was classified as a Queens soil (Cann et al, 1954) on a 6 percent slope. Site 2 was classified as a Hansford soil (Webb et al, 1991) on a 2 percent slope. A brief description of each soil is given in Tables 1 and 2.

Table 1. Description of soil at site 1 - Queens soil.

Imperfectly drained. 6 % slope					
Horizon	Depth (cm)	Description	* Particle Size Analyses		
			% Sand	% Silt	% Clay
Ap	0 - 20	loam, friable	36	47	17
Bmgj	20 - 40	loam, friable	48	38	14
Cgj	40 - 80	loam, firm	37	39	24

** Particle size analyses was completed by the Analytical Services Lab of the Plant Industry Branch of the Nova Scotia Department of Agriculture and Marketing.*

Table 2. Description of soil at site 2 - Hansford soil.

Imperfectly drained. 1 to 2 % slope.					
Horizon	Depth (cm)	Description	* Particle Size Analyses		
			% Sand	% Silt	% Clay
Apg	0 - 20	gravelly sandy loam, friable	45	46	9
Bg	20 - 31	gravelly sandy loam, friable	41	47	12
C1	31 - 55	gravelly sandy loam, firm	39	50	11
C2	55 - 80	gravelly sandy loam, firm	36	55	9

** Particle size analysis was completed by the Analytical Services Lab of the Plant Industry Branch of the Nova Scotia Department of Agriculture and Marketing.*

Soil density and hydraulic conductivity

Soil density and hydraulic conductivity data were collected at site 2 in the summer of 1989 before and after subsoiling. In the spring of 1990, soil density data was collected at site 1. Both sites were sampled again in the summer of 1992 to determine the residual effects of subsoiling. Hydraulic conductivity data was collected for site 2 only as site 1 was seeded before measurements could be taken.

Soil density

Soil density was measured using a CPN MC-3 Portaprobe. Data was collected for three depths (15-20, 15-30 and 15-45 cm) at site 2 and for 2 depths (15-30 and 15-45 cm) at site 1. Measurements were taken at 9 locations in each plot for a total of 27 sites for each treatment (3 replicates of each treatment). A schematic diagram and a brief description of the CPN MC-3 Portaprobe is included in Appendix A.

Soil hydraulic conductivity

Hydraulic conductivity was measured at site 2 using a Guelph permeameter. Nine sites were tested per plot at 2 soil depths (30 and 45 cm). This was repeated in 1992. A schematic diagram and a brief description of the Guelph permeameter is included in Appendix A.

Soil trafficability

In the spring of 1990, the trafficability of both sites was assessed by measuring the soil shear strength and the soil penetration resistance. This was repeated in the spring of 1991. In addition, in 1991 soil samples were collected to determine soil moisture content on a volume basis.

Soil shear strength

Shear vane readings were taken using a Geonor H60 field inspector vane tester. Vanes were four bladed of either a 20 by 40 mm or a 25.4 by 50.8 mm size. The larger size vane was used when the soil had low shear strength, the smaller when the soil had higher shear strength. A minimum of three readings were taken for each replicate for a total of nine readings for each treatment. Readings were started April 17, 1990 and continued until the site was cultivated. In 1991 readings were taken from May 4 to May 6 and May 8 to May 10 following a rainfall event. A schematic diagram and a brief description of the Geonor H60 shear vane is included in Appendix A.

Soil penetration resistance

Cone penetrometer readings were taken using a Rimik CP10 recording cone penetrometer fitted with a 12.9 mm diameter, 30 degree, stainless steel cone. Readings were taken every 1.5 cm to a depth of 45 cm. A minimum of three readings were taken for each replicate with a total of nine readings (minimum) for each treatment. Readings were collected over the same time period as the shear vane readings. A brief description of the Rimik cone penetrometer is included in Appendix A.

Soil moisture

Soil samples of a known volume were taken only in the spring of 1991 to determine volumetric soil moisture. Two samples were collected from the 5 to 10 cm soil depth for each plot. Soil moisture content was determined on a volumetric basis by taking samples of a known volume and oven drying them for 24 hours at 105°C. The dried samples were weighed and the volumetric water content was determined by using method 2.413 as outlined in McKeague (1978).

Crops

In 1990, barley was seeded at site 1, followed by faba beans in 1991 and a permanent grass/legume mixture in 1992.

In 1990, site 2 was planted to two forage crops, alfalfa/timothy and red clover/timothy. Considerable winterkill occurred at the site during the winter of 1990/1991. Over 99% of the red clover died while more than 90% of the alfalfa did not survive. As a result, the site was reseeded in the spring of 1991.

At site 2 in 1990, 1991 and 1992, plant counts of a 0.25 square meter area were taken 3 meters and 6 meters from the tile lines and directly over the tile lines. Alfalfa/timothy and red clover/timothy yields were taken by harvesting a strip perpendicular to the tile drains with 9 samples per plot, including over and between drain lines. Yield measurements were taken in 1992. Root count data was collected at site 2 in 1992 at soil depths of 20, 30 and 45 cm. The data from the root counts was grouped into four categories of root sizes; less than 1 mm, between 1 and 2 mm, between 2 and 3 mm and greater than 3 mm.

Statistical analysis (ANOVA) was performed on the soil density, hydraulic conductivity and crop yield data.

RESULTS AND DISCUSSION

Soil density and hydraulic conductivity

Soil density

Soil density was measured at site 2 prior to subsoiling in July 1989. The soil density was measured again in August 1989 after the plots were subsoiled and also, three years later, in July 1992.

In the initial year after subsoiling, the subsoiling treatments had soil densities approximately 0.3 g/cm^3 less than the control treatment for the 15-30 cm depth. Three years later, the mean soil densities of the subsoiled treatments were very similar to that of the control treatment (1.38 g/cm^3 and 1.36 g/cm^3 respectively).

For the alfalfa and red clover plots, subsoiling significantly decreased soil density in the initial year after subsoiling for all three depths but three years later there was no significant difference between subsoiled and non-subsoiled plots (1% confidence level).

In addition, the 50 cm subsoiled treatment had a significantly lower density than the 35 cm subsoiled treatment for the 15-45 cm depth in 1989 (immediately after subsoiling). The mean densities for the various depths and treatments for 1989 (immediately after subsoiling) and 1992 as well as the standard error of the mean is shown in Table 3.

Table 3. Means for soil density data (g/cm^3) at site 2.

Treatment	15-20 cm depth		15-30 cm depth		15-45 cm depth	
	1989	1992	1989	1992	1989	1992
Control	1.24	1.15	1.51	1.36	1.64	1.55
SS 35	1.08	1.16	1.18	1.38	1.48	1.54
SS 50	1.08	1.17	1.21	1.38	1.31	1.52
S.E. means	0.022	0.021	0.012	0.018	0.021	0.013

At site 1, the plots were subsoiled in September 1989. Soil density was measured in the spring of 1990 and in the summer of 1992. In 1990, for the 15-30 cm soil depth, the 50 cm subsoiled treatment compared to the other treatments had significantly lower density (1.35 g/cm^3 versus 1.47 g/cm^3 and 1.51 g/cm^3) at the 5% confidence level. In 1992, the 50 cm subsoiled treatment had significantly lower density than the 35 cm subsoiled treatment (1.50 g/cm^3 versus 1.63 g/cm^3) for the 5% confidence level. At the 15-45 cm soil depth, the plots subsoiled to 50 cm had significantly lower density than the other treatments in 1990 and 1992 at the 5% and 1% confidence levels respectively. The means and the standard error of means for the soil density data from site 1 is shown in Table 4.

Table 4. Means for soil density data (g/cm^3) at site 1.

Treatments	15-30 cm depth		15-45 cm depth	
	1990	1992	1990	1992
Control	1.51	1.57	1.61	1.65
SS 35	1.47	1.63	1.58	1.68
SS 50	1.35	1.50	1.49	1.55
S.E. means	0.037	0.029	0.031	0.020

Graphs showing soil densities for the 15-30 and 15-45 cm soil depths at site 1 and the 15-20, 15-30 and 15-45 cm soil depths at the alfalfa and red clover portion of site 2 are in Appendix B.

Soil hydraulic conductivity

Data on hydraulic conductivity was collected before, immediately after and three years after subsoiling at site 2 only. For the 30 cm soil depth, the hydraulic conductivities of the two subsoiled treatments immediately after subsoiling was significantly higher (1% confidence level) than the non-subsoiled plots. Three years later there was no significant difference between hydraulic conductivities of the subsoiled treatments and the non-subsoiled plots. This was the case for both the alfalfa and red clover sections of site 2.

Table 5. Means for hydraulic conductivity (cm/hr) at site 2.

Treatments	30 cm Depth		45 cm Depth	
	1989 After SS	1992	1989 After SS	1992
Control	0.59	1.33	0.41	0.89
SS 35	3.03	1.34	0.80	1.47
SS 50	5.01	1.24	2.42	1.21
S.E. means	0.540	0.197	0.201	0.275

At the 45 cm soil depth, the 50 cm subsoiled treatment had significantly higher hydraulic conductivities than the 35 cm subsoiled treatment and the control treatment immediately after subsoiling but not three years later. The 35 cm deep subsoiled plots had slightly higher hydraulic conductivities than the control plots immediately after subsoiling and three years later but the difference was not statistically significant.

Appendix C has graphs showing the hydraulic conductivities for the 30 and 45 cm soil depths at the alfalfa and red clover plots.

Soil trafficability

Soil trafficability data was collected in the spring of 1990. Upon analyses of the 1990 data it was determined that data should be collected at a set interval following a rainfall event that saturated the soil. In 1991, trafficability data was collected for three days following two separate rainfall events. Data from site 2 was not separated into an alfalfa and red clover section as the crops had been winter killed.

The soil shear strength measurements and soil moisture measurements were taken at a soil depth of 5-10 cm. Cone penetrometer data was analyzed for the 6 and 9 cm soil depths.

Soil shear strength

The soil shear strength at both sites increased each day following a rainfall event for each treatment. There was no apparent difference in soil shear strength among treatments.

The data collected was very variable as a result of two factors, soil conditions which affect trafficability (which we are trying to measure) and soil conditions which affect the measuring device such as stones, roots and cracks in the soil. Because the data was so variable, it was difficult to draw conclusions unless there was a wide difference in the averages.

Soil penetration resistance

Soil penetration resistance for both sites at the 6 and 9 cm soil depths increased from the first day after a rainfall to the second day for all treatments. The penetration resistance for all treatments remained the same from day 2 to day 3. There is no difference in penetration resistance between either the subsoiled plots or the non-subsoiled plots.

The penetrometer data at site 2 was difficult to collect because of the gravel and stones present at the soil surface and in the soil profile which inhibited proper insertion of the penetrometer rod into the soil at a constant rate.

Soil moisture

At site 2 only a slight difference was found between the subsoiled and control plots. The control plots were slightly higher than the subsoiled plots. At site 1 the soil moisture was substantially higher for the subsoiled plots on two of the three days.

The data, however, was highly variable. There was little change in soil moisture from the first day to the third day after the rainfall.

The cone penetrometer, soil shear and soil moisture data is presented as graphs in Appendix D.

Crops

Plant counts

The intent of taking plant counts was to measure plant persistence by comparing the same 0.25 square meter area from each plot year after year. The method used to locate this area consisted of using a system of measured ropes. After reviewing the data, it became apparent that these ropes were not locating the same spot each year. Even though the exact area was not located, the plant count data is still used to represent each plot. The means for plant count data for 1991 and 1992 at site 2 is shown in Table 5. The means are based on 6 measurements in each plot replicated three times.

Table 6. Means for plant counts per square meter for 1991 and 1992 at site 2.

Treatment	Alfalfa		Red clover	
	1991	1992	1991	1992
Control	88	21	54	26
SS 35	72	37	49	32
SS 50	86	38	69	60

The data in Table 6 indicates that the subsoiled plots had a higher percent of plants surviving from 1991 to 1992 than the non-subsoiled plots. The data, however, was highly variable so no conclusion can be made.

Root counts

Root counts were taken at soil depths of 20, 30 and 45 cm in the red clover and alfalfa sections of site 2 in July 1992.

In the alfalfa portion of the field most of the roots were one millimeter or less in diameter. At the 20 cm depth there were approximately four times more roots of the 1 mm or smaller size than at the 30 cm depth. The 35 cm deep subsoiled plots had close to twice as many 1 mm or smaller roots as the other treatments at both depths.

For the red clover plots the greatest number of roots were of the 1 mm or smaller size but there was a more even distribution of root sizes than the alfalfa plots, especially at the 20 cm soil depth. There was no difference in root counts among treatments for the red clover plots.

Graphs showing the root count data for the 20 and 30 cm soil depths for the red clover plots and alfalfa plots are shown in APPENDIX E. There are no graphs showing the root count data for the 45 cm soil depth at site 2 as there were no roots found at that depth.

Yields

At site 1, the barley crop in 1990 suffered severe disease infestation resulting in poor yields on all treatments. In 1991, the faba bean crop was not harvested due to inclement weather in the fall. In 1992, the field was seeded to a permanent grass/legume mix and yields were not taken.

In 1990, the two forage crops (alfalfa/timothy and red clover/timothy) were planted at site 2. Considerable winterkill of the legumes occurred at the site during the winter of 1990/1991. Over 99% of the red clover died while more than 90% of the alfalfa did not survived. As a result, the site was reseeded in the spring of 1991. Due to the dry weather following seeding in 1991 little of the timothy seed germinated resulting in dominant legume stands. The alfalfa/timothy and red clover/timothy were harvested in June 1992. Table 7 shows the means for alfalfa/timothy and red clover/timothy yields at site 2.

Table 7. Means for alfalfa/timothy and red clover/timothy yields (kg/ha) at site 2.

Treatment	Alfalfa/timothy	Red clover/timothy
Control	1123	1522
SS 35	1140	2141
SS 50	1375	2631
S.E. means	159.8	159.8

There was no significant difference among treatments for either the alfalfa/timothy or red clover/timothy yields. Although yields are not significantly different, there is a trend towards higher yields with increased depth of subsoiling. This trend also applies for yields taken over tile lines (0-1.5 meters from tiles) and yields taken between tile lines (1.5-4.6 and 4.6-7.6 meters from tiles). Appendix E has graphs showing the average alfalfa/timothy and red clover/timothy yields for different areas of the plots in relation to the distance from the tile drains. The graphs also show yields over tile lines are at least 30 percent greater than yields 4.6-7.6 meters from the tile lines.

The yields from all treatments were poor from an economical standpoint but it was thought that the plots would have had higher yields if the timothy had better germination. There was no second cut of forages in 1992 because cows inadvertently got on the project site.

CONCLUSIONS

Subsoiling in combination with tile drainage on level or nearly level land (less than 2 % slope) did improve the survival rate of red clover for two years. Red clover yields were improved by subsoiling but not to an economical level. Yields may have been higher if timothy seed germination rates had been better. Survival rate and yields for alfalfa were similar among all treatments. Substantial winterkill makes it impossible to draw conclusions about the benefits of subsoiling to crop performance. Subsoiling did reduce soil density and improve hydraulic conductivity in the first year. This effect on the soil is not evident after 3 years. Root distribution was evaluated at three depths in the soil profile. This was not adequate. Future research should carefully evaluate root distribution in the whole profile in order to determine differences if present as a result of subsoiling.

No conclusion can be made regarding the effect of subsoiling on annual crops. It is recommended that future work on subsoiling assessment use perennial forages as the indicator crop as it is too difficult to evaluate annual crops unless the researchers are prepared to seed each treatment when they become trafficable.

The presence of stones and roots in the soil affected the precision of measurement for the cone penetrometer and shear vane. For the soils used in this study, it would take a fairly large difference in soil strength for either the cone penetrometer or shear vane to determine differences in soil strength because of the high variability in the data. From our data it appears that soil trafficability was not affected by the subsoiling treatments.

This study indicates that additional research should be continued to clarify the effect of subsoiling on soil trafficability on various soil types. In particular, subsoiling should be evaluated on land with various slopes. In addition, future research should examine the effect of soil amendments, such as lime, used in combination with subsoiling.

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APPENDIX A - Equipment

CPN MC-3 PORTAPROBE

The MC-3 PORTAPROBE operates by emitting gamma radiation into the soil. Some of the gamma radiation will pass through the soil and be detected by the detector in the MC-3. A high density soil will absorb more gamma radiation than a low density soil.

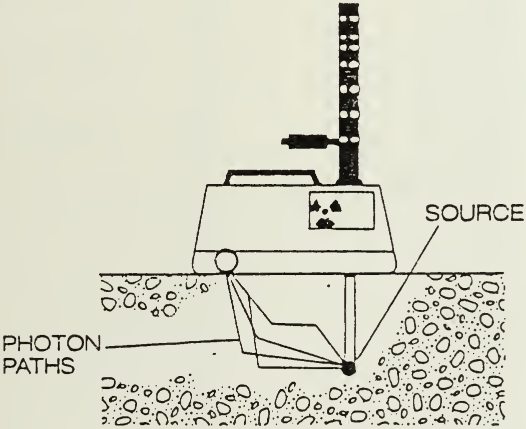

Figure 7. CPN MC-3 Portaprobe.

GUELPH PERMEAMETER

The Model 2800K1 Guelph Permeameter is a constant-head device which operates on the Mariotte siphon principle and provides a quick and simple method for determining field saturated hydraulic conductivity in the field.

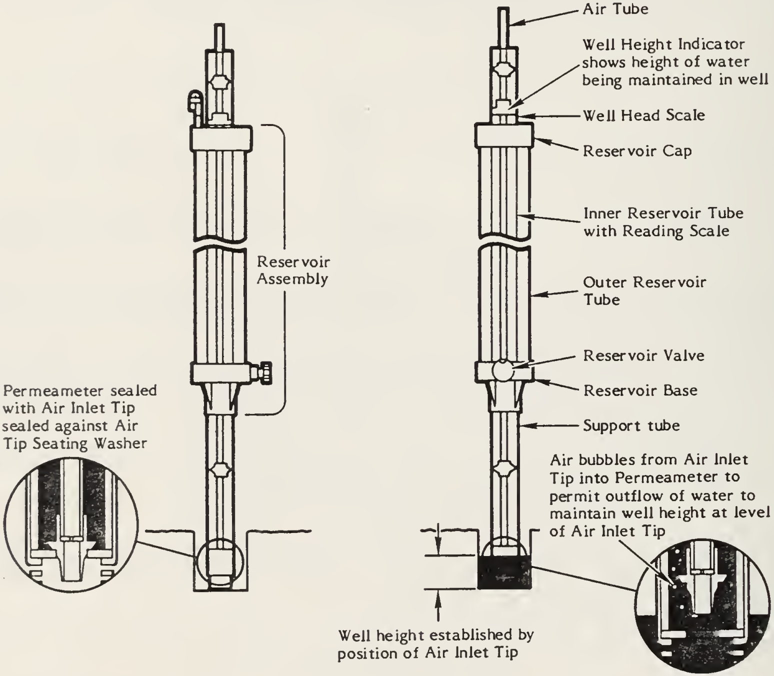
Air Tube
Well Height Indicator shows height of water being maintained in well
Well Head Scale
Reservoir Cap
Inner Reservoir Tube with Reading Scale
Reservoir Assembly
Outer Reservoir Tube
Reservoir Valve
Reservoir Base
Support tube
Permeameter sealed with Air Inlet Tip sealed against Air Tip Seating Washer
Air bubbles from Air Inlet Tip into Permeameter to permit outflow of water to maintain well height at level of Air Inlet Tip
Well height established by position of Air Inlet Tip

Figure 8. Guelph permeameter.

GEONOR INSPECTION VANE TESTER H-60

The Geonor field inspection vane tester measures the shear strength of soils. The range of the instrument is from 0-26 T/m^2. The procedure for using the shear vane consists of pushing the vanes into the soil and turning the handle. When the soil shears, a graduated scale on the handle will show the soil shear strength.

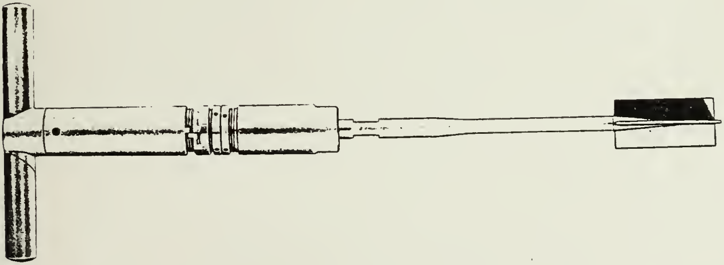

Figure 9. Geonor H60 shear vane.

RIMIK CP10 CONE PENETROMETER

The Rimik CP10 is a cone penetrometer and a data logger with 64k of data storage memory. To operate the Rimik CP10, slowly push the probe into the soil to a depth of 450 mm. Then withdraw the probe and move to the next site. The data is automatically saved on the datalogger.

APPENDIX B - Soil density graphs

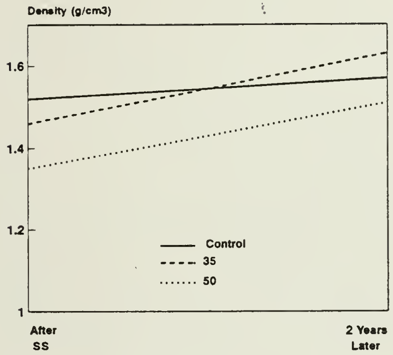

Figure 10. Average densities for the 15-30 cm soil depth at site 1.

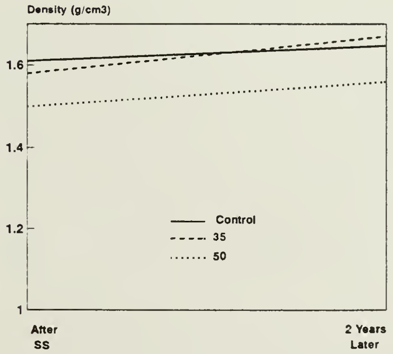

Figure 11. Average densities for the 15-45 cm soil depth at site 1.

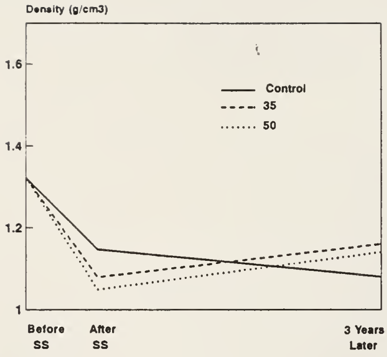

Figure 12. Average densities for the 15-20 cm soil depth on the alfalfa portion of site 2.

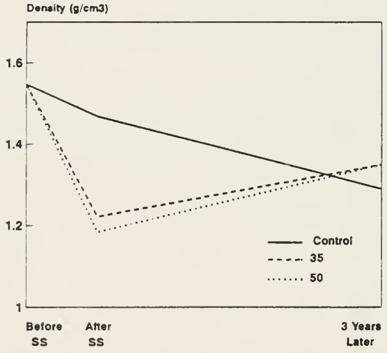

Figure 13. Average densities for the 15-30 cm soil depth on the alfalfa portion of site 2.

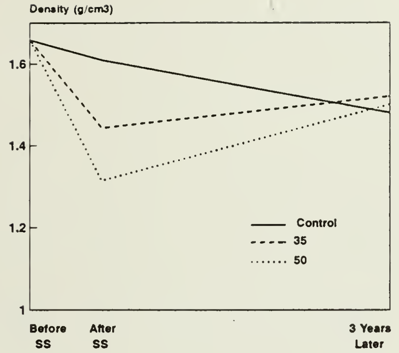

Figure 14. Average densities for the 15-45 cm soil depth on the alfalfa portion of site 2.

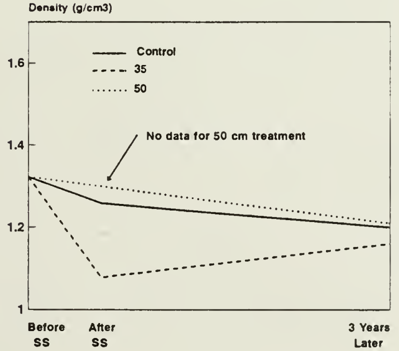

Figure 15. Average densities for the 0-20 cm soil depth on the red clover portion of site 2.

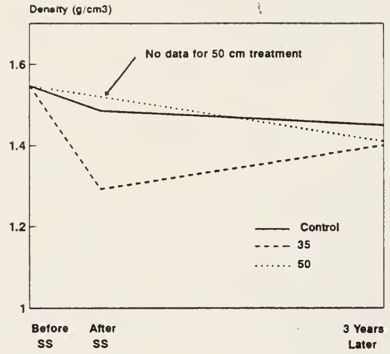

Figure 16. Average densities for the 0-30 cm soil depth on the red clover portion of site 2.

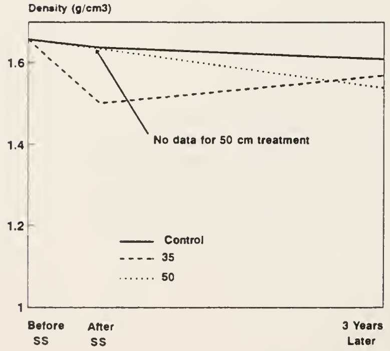

Figure 17. Average densities for the 15-45 cm soil depth on the red clover portion of site 2.

APPENDIX C - Hydraulic conductivity graphs

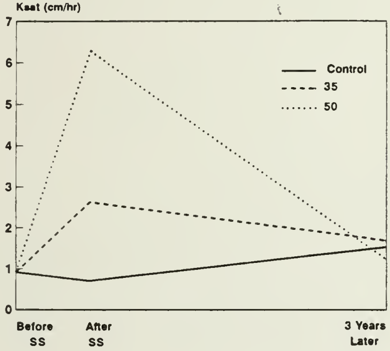

Figure 18. Average hydraulic conductivities for the 30 cm soil depth at site 2 (alfalfa).

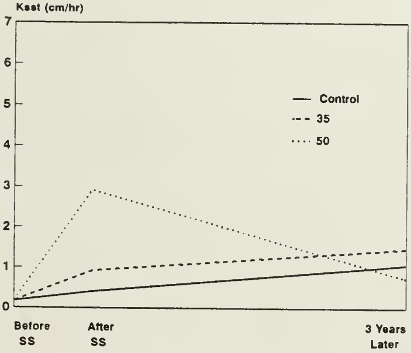

Figure 19. Average hydraulic conductivities for the 45 cm soil depth at site 2 (alfalfa).

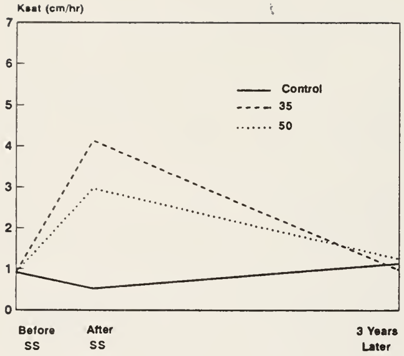

Figure 20. Average hydraulic conductivities for the 30 cm soil depth at site 2 (red clover).

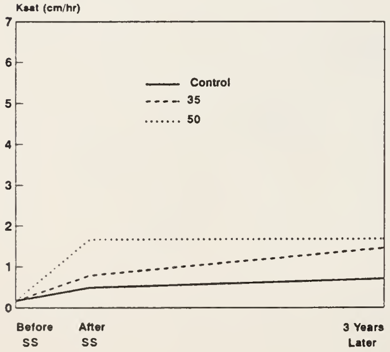

Figure 21. Average hydraulic conductivities for the 45 cm soil depth at site 2 (red clover).

APPENDIX D - Trafficability graphs

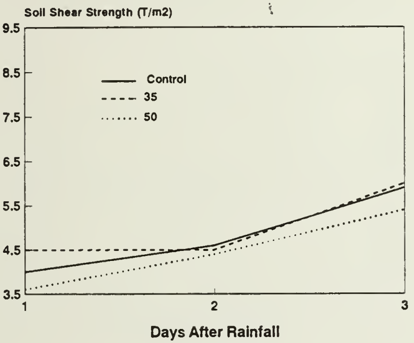

Figure 22. Average soil shear strength for the 5-10 cm soil depth at site 1.

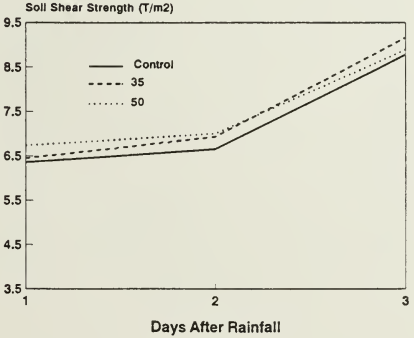

Figure 23. Average soil shear strength for the 5-10 cm soil depth at site 2.

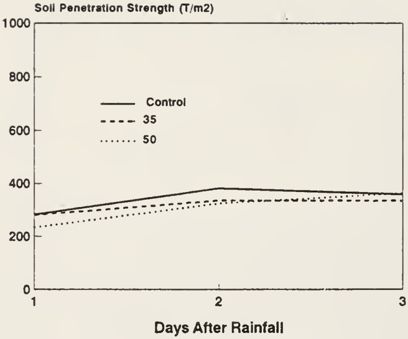

Figure 24. Average soil penetration strength for the 6 cm soil depth at site 1.

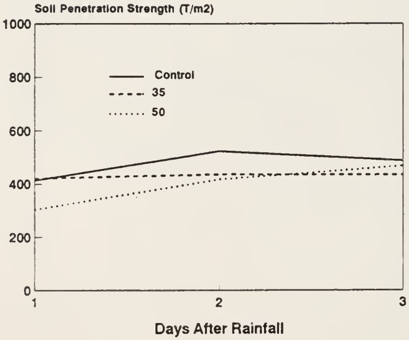

Figure 25. Average soil penetration strength for the 9 cm soil depth at site 1.

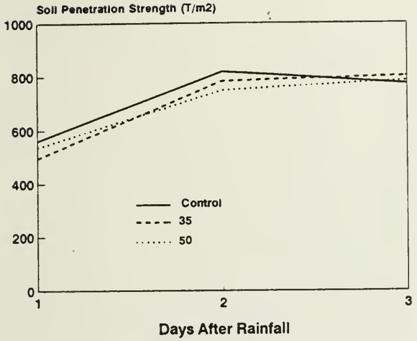

Figure 26. Average soil penetration strength for the 6 cm soil depth at site 2.

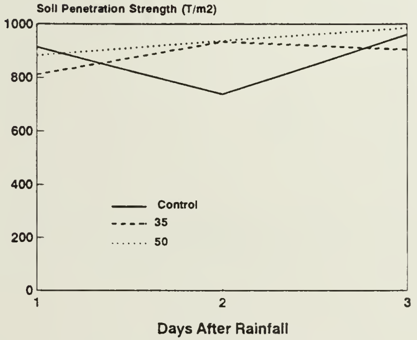

Figure 27. Average soil penetration strength for the 9 cm soil depth at site 2.

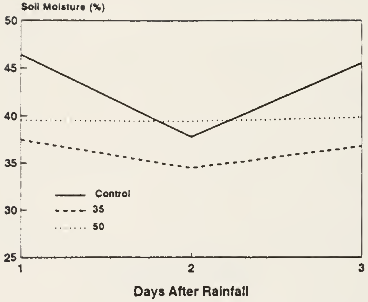

Figure 28. Average soil moisture for the 5-10 cm soil depth at site 1.

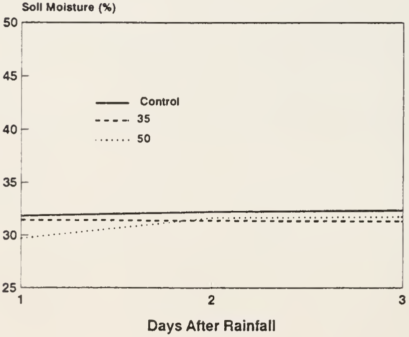

Figure 29. Average soil moisture for the 5-10 cm soil depth at site 2.

APPENDIX E - Root counts and yield graphs

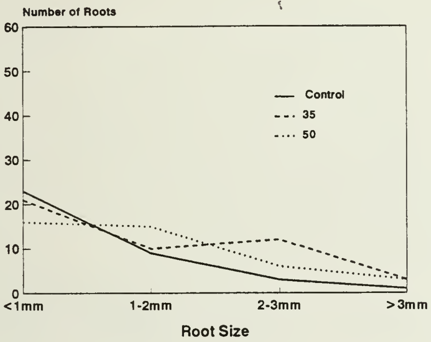

Figure 30. Number of roots for the 20 cm soil depth at the red clover portion of site 2.

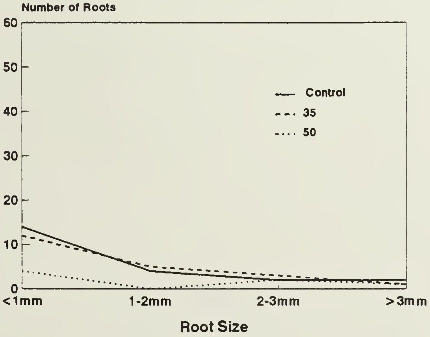

Figure 31. Number of roots for the 30 cm soil depth at the red clover portion of site 2.

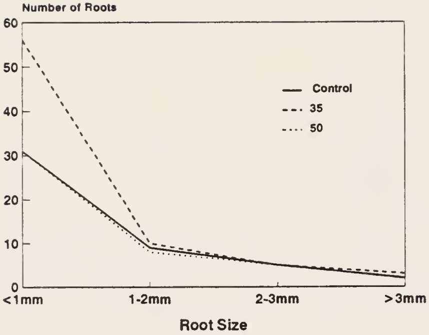

Figure 32. Number of roots for the 20 cm soil depth at the alfalfa portion of site 2.

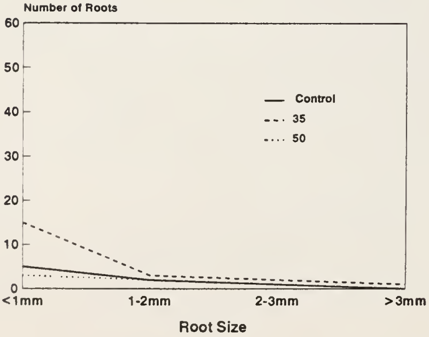

Figure 33. Number of roots for the 30 cm soil depth at the alfalfa portion of site 2.

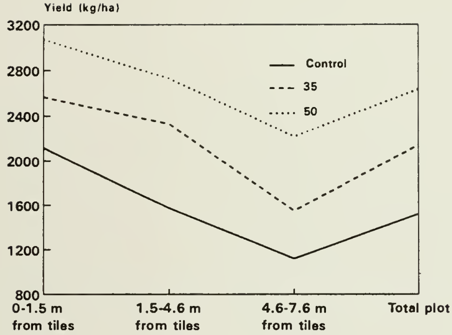

Figure 34. Red clover/timothy yields from June 1992.

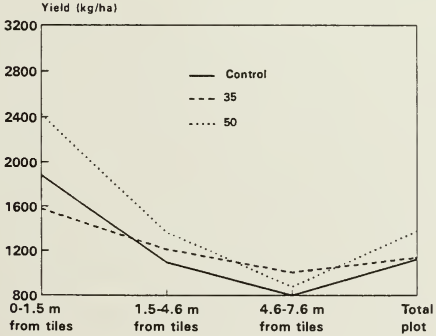

Figure 35. Alfalfa/timothy yields from June 1992.

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